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(Dr. C. H. Chen, Principal Investigator)



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SOME NEW RESULTS
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Technical rpt.,

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Abstract

A brief review is made of current problems on computer image processing and recognition. New and unpublished results of a rotation-invariant operator and an adaptive filtering approach are then presented. Finally a sequential binary decision procedure for reconnaissance image classification is discussed.

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Some New Results on Image Processing and Recognition

C. H. Chen

I. Current Problems on Image Processing and Recognition

Current signal processing and pattern recognition problems with images may be summarized as follows:

1. Real-time or near real-time requirements.
2. Time-varying images.
3. Large data base and the associated data base management.
4. Data storage and display.
5. New processing and recognition algorithms.
6. Parallel versus sequential operations.
7. Software and hardware development.
8. Picture representation and languages.

The above list is, of course, incomplete and all problems are not of equal importance. Problem areas are obviously application dependent. This paper will deal with problem #5 stated above with applications in the reconnaissance images including FLIR imagery and aerial photographs.

II. A Rotation-Invariant Digital Operator

The Laplacian operator is rotation invariant only for continuous spatial variables. For discrete variables, the deblurred picture as a result of Laplacian operation is [1]

$$\begin{aligned} g(i,j) &= f(i,j) - \nabla^2 f(i,j) \\ &= 5f(i,j) - [f(i-1, j) + f(i+1, j) + f(i, j-1) + f(i, j+1)] \end{aligned} \quad (1)$$

where $f(i,j)$ is for the gray level of the original picture. Taking the z-transform of Eq. (1) we have

$$G(z_1, z_2) = F(z_1, z_2) [5 - (z_1 + z_1^{-1} + z_2 + z_2^{-1})]$$

The transfer function of the deblurring operation is

$$H(z_1, z_2) = 5 - (z_1 + z_1^{-1} + z_2 + z_2^{-1})$$

which has frequency response

$$H(\omega_1, \omega_2) = 5 - 2 \cos \omega_1 - 2 \cos \omega_2 \quad (2)$$

where $\omega_1 = \omega \cos \theta$, $\omega_2 = \omega \sin \theta$. Thus $H(\omega_1, \omega_2)$ is not rotation-invariant as it depends on θ .

Now if $H(\omega_1, \omega_2)$ takes the form $a + b(\omega_1^2 + \omega_2^2)$, it will be rotation-invariant.

Taking the Fourier series approximation,

$$\omega_1^2 = a_0 + a_1 \cos \omega_1 + a_2 \cos 2\omega_1$$

$$\omega_2^2 = a_0 + a_1 \cos \omega_2 + a_2 \cos 2\omega_2$$

for $-\frac{\pi}{2} \leq \omega_1, \omega_2 \leq \frac{\pi}{2}$, we have

$$H(\omega_1, \omega_2) = b_0 + b_1(\cos \omega_1 + \cos \omega_2) + b_2(\cos 2\omega_1 + \cos 2\omega_2) \quad (3)$$

or in z-transform

$$H(z_1, z_2) = b_0 + \frac{b_1}{2} (z_1 + z_1^{-1} + z_2 + z_2^{-1}) + \frac{b_2}{2} (z_1^2 + z_1^{-2} + z_2^2 + z_2^{-2})$$

In spatial domain we can write

$$\begin{aligned} g(i, j) = & b_0 f(i, j) + \frac{b_1}{2} [f(i-1, j) + f(i+1, j) + f(i, j-1) + f(i, j+1)] \\ & + \frac{b_2}{2} [f(i-2, j) + f(i+2, j) + f(i, j-2) + f(i, j+2)] \end{aligned} \quad (4)$$

Thus we can consider a good approximation to the ideal rotation-invariant

Laplacian operator as

$$\begin{aligned} \nabla^2(i, j) = & -\frac{1}{2} a_1 [f(i-1, j) + f(i+1, j) + f(i, j-1) + f(i, j+1)] \\ & -\frac{1}{2} a_2 [f(i-2, j) + f(i+2, j) + f(i, j-2) + f(i, j+2)] \\ & - 2 a_0 f(i, j) \end{aligned} \quad (5)$$

Eq. (5) clearly is a modification of existing digital Laplacian operation in that pixels of distance 2 are also included in the computation. The use of this new local operation to an FLIR imagery with tank as object is illustrated in Fig. 1. Here Fig. 1(a) is the Laplacian picture while Fig. 1(b) is the result of

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Fig. 1(a)

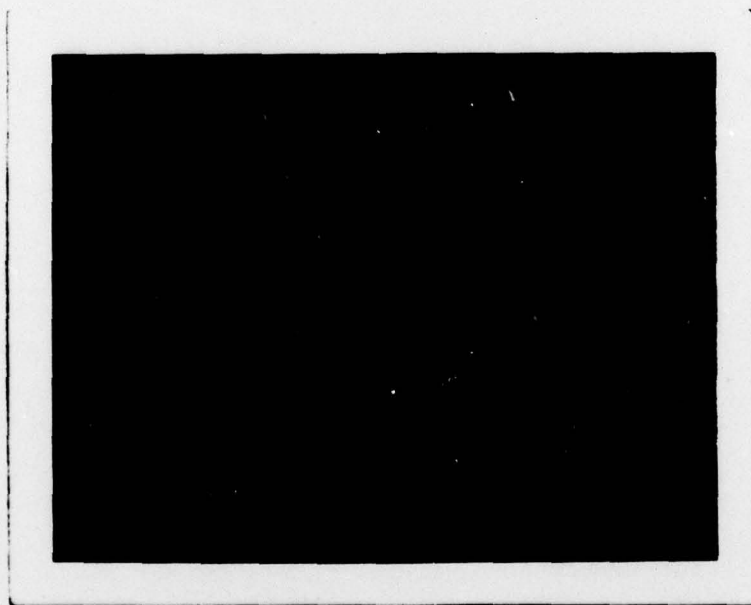


Fig. 1(b)

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applying the new operator. The improvement in the lower boundary of the tank is particularly evident. This new operator should in general be very useful for objects with curved boundary.

Related operators considered are the modified gradient [2] and the multi-derivative operators [3].

III. An Adaptive Filtering Approach

Without the object boundaries, a reconnaissance image may be modeled as a homogeneous random field. Kalman filtering can be used to smooth the random field. The object boundaries cause abrupt change in gray levels. An adaptive filtering method has been proposed [4] for detection and estimation of the jumps by using Kalman filtering and generalized likelihood ratio techniques. The method is designed for systems subject to possible component failures and the tracking of vehicles capable of abrupt maneuvers. The generalized likelihood ratio serves as a monitor of the jumps and the jumps detected are used to update the state estimate in the state equation. The method is very suitable to the enhancement of reconnaissance images since the boundaries will not be blurred by the Kalman filtering due to the adaptive behavior of the algorithm. The state of the dynamical system is the gray level of a pixel. If several pixels are considered then the state is a vector quantity. The random field is modeled as a Markov chain and the recursive filtering operation can be performed efficiently. The detection by the generalized likelihood ratio, however, makes use of several data points in a data window. Thus false alarm possibility can be minimized. Computer results are given in Figs. 2 and 3. Figure 2(a) shows artificial data with one positive jump and additive noise. The result of adaptive filtering is shown in Fig. 2(b). The noise removal is very obvious while the jump is not blurred at all. The initial set of data points rises rapidly to a constant level, and then, after a jump, to another constant level.

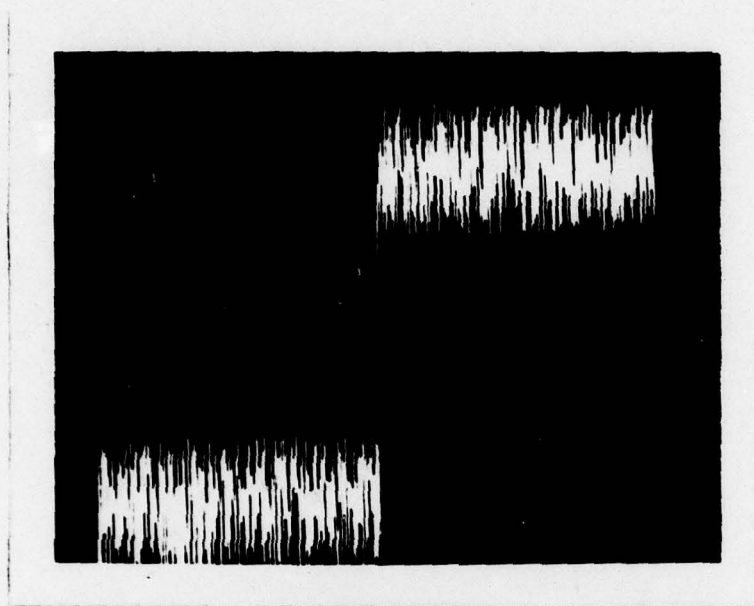


Fig. 2(a).

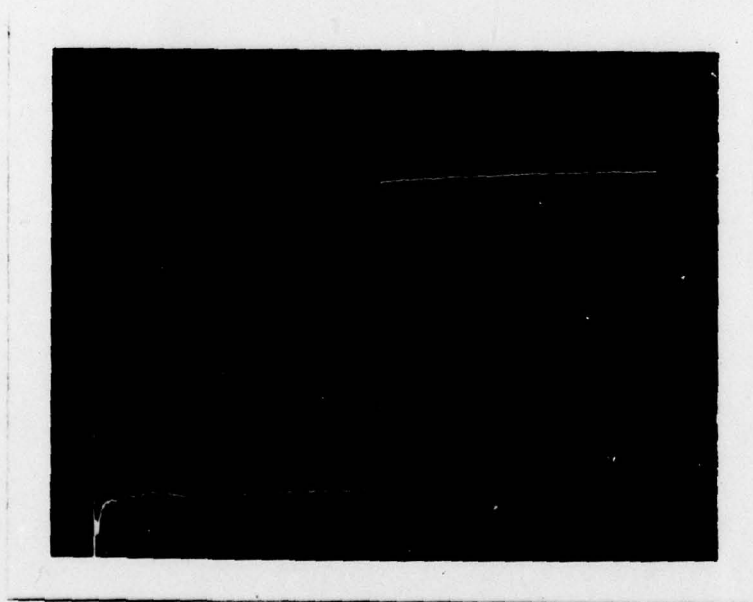


Fig. 2(b)

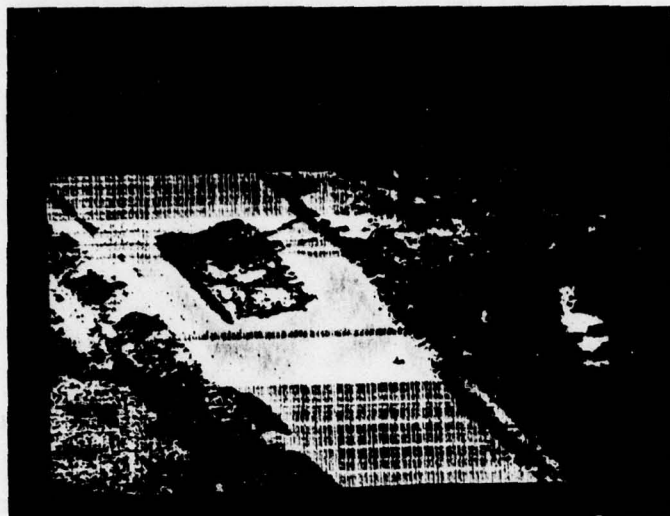


Fig. 3(a)



Fig. 3(b)

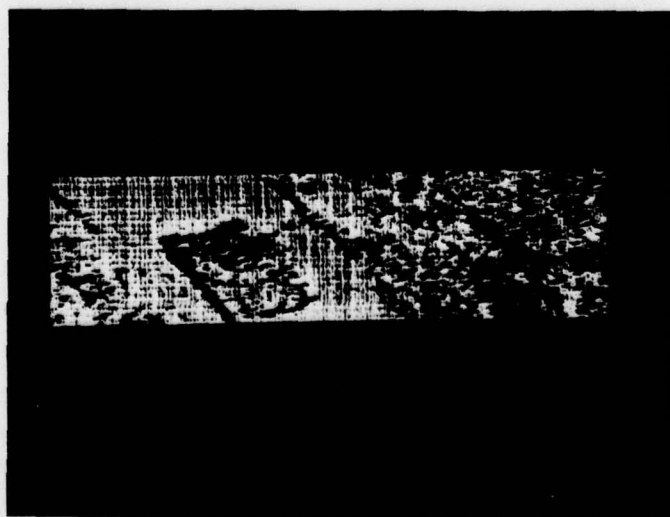


Fig. 3(c)

Figure 3(a) is the result of adaptive filtering on real aerial photograph also with tank as an object moving on a road. The picture clearly shows the object from its background. If additive Gaussian noise is added to the original picture, we have Fig. 3(b). The road now cannot be distinguished from its background. Figure 3(c) is the result of adaptive filtering. Considering the small signal-to-noise ratio, the improvement is significant. The filtering operation is performed line by line. Parallel operation may be used to speed-up the processing.

The adaptive filtering method offers a very effective procedure to enhance the image without blurring the object boundaries. The additive and multiplicative noises are suppressed by the filtering operation. The technique is also suitable for time-varying pictures and offers more flexibility than conventional smoothing operations.

IV. The Image Recognition Problem

The recognition problem considered here is the detection and location of the target which is a man-made object. Examples of other recognition problems not considered here are the aircraft identification, discrimination among different object, etc. For human visualization, object/background segmentation serves the purpose of separating the object at a given location from the surrounding background. The joint use of gray level, edges, and texture has been considered for segmentation of FLIR imagery [5]. For the recognition problem we consider, the aerial photograph is first partitioned into a number of small segments. Features are extracted from each segment including texture, average gradient measure, entropy measure, etc. [6]. As the features are of different nature, statistical classification is not appropriate. A sequential binary decision tree is used which starts with the best feature and examines the decision made by each feature sequentially. Additional features are used only when the decisions are not consistent! The classification scheme was able to provide correct recognition for all images we had available.

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